WORKSHOP ON THE PHENOMENON KNOWN AS "EL NIÑO"

Organized within the
International Decade
of Ocean Exploration (IDOE)

Under the Sponsorship of
IOC, Unesco, FAO and WMO

Guayaquil, Ecuador
4-12 December 1974

REPORT

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REPORT OF THE

WORKSHOP ON THE PHENOMENON KNOWN AS "EL NIÑO"

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4-12 December 1974

Organized within the

INTERNATIONAL DECADE OF OCEAN EXPLORATION (IDOE)

UNDER THE SPONSORSHIP OF IOC, Unesco, FAO AND WMO

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, September 1975

EDITORIAL NOTE

This publication forms part of the Proceedings of the Workshop on the Phenomenon known as "El Niño", organized within the International Decade of Ocean Exploration (IDOE) jointly by IOC, Unesco, FAO and WMO, held in Guayaquil, Ecuador from 4 to 12 December 1974. The present volume, issued by FAO in its FAO Fisheries Reports series, contains the report of the Workshop, and the titles of papers presented or distributed at the Workshop. The texts of the contributions will be published in English by IOC and in Spanish by FAO.

The views expressed in this report are those of the authors and do not necessarily reflect the policies of the sponsoring agencies.

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1. BACKGROUND

During the eighth session of its Assembly, the Intergovernmental Oceanographic Commission (IOC) adopted Resolution VIII-17 in which it instructed the Secretary to organize jointly with the Food and Agriculture Organization of the United Nations (FAO) and the World Meteorological Organization (WMO) a Workshop on the phenomenon of "El Niño":

(a) to analyse the present state of knowledge concerning the phenomenon;

(b) to identify the key questions that must be answered to allow understanding and prediction of the phenomenon;

(c) to devise a cooperative scientific research programme, with priorities, with the direct participation of the coastal countries affected by this phenomenon and with the collaboration and coordination of the IOC and other Specialized Agencies of the United Nations;

(d) to formulate proposals for a study on the interaction between this phenomenon and the biological resources of the region.

The Steering Committee which was formed to plan this Workshop, held its first meeting in Callao, Peru, on 17 and 18 January 1974. The members of this Committee, under the chairmanship of Dr. Warren Wooster, reached the following conclusions:

(i) Although the resolution stresses the set of anomalous conditions known as "El Niño", the workshop should also be concerned with variations in the total coupled systems of atmosphere–ocean–biosphere in the eastern South Pacific Ocean.

(ii) The goal of the investigations to be considered by the workshop should be to predict variations in the ocean environment of the region and the consequences of such variations, and in particular to predict the development of "El Niño" conditions and their consequences.

Dr. Rómulo Jordán (Peru) was invited to serve as Chairman of the workshop.

It was decided that after preliminary discussions, the workshop would divide into two groups: a biological group to be chaired by Dr. Alan Longhurst, with Dr. Geoffrey L. Kesteven as rapporteur; and a physical group to be chaired by Dr. Merritt Stevenson, with Dr. Warren Wooster as rapporteur.

Attendance at the presentations and discussions on the review papers was open to all; the workshop was, however, restricted to the invited experts.

The workshop was sponsored by the Intergovernmental Oceanographic Commission (IOC), the United Nations Educational, Scientific and Cultural Organization (Unesco), the Food and Agriculture Organization of the United Nations (FAO) and the World Meteorological Organization (WMO), with financial assistance (for United States participants) from the National Science Foundation of the U.S.A., Office of the International Decade of Ocean Exploration.

2. RECOMMENDATIONS

GENERAL

1. Considering that it is important for the scientific community in general to know of the contributions presented at the workshop, as a consequence of the research carried out by the countries of the west coast of South America, it is recommended:

that the papers presented at the workshop by scientists from the region be published as soon as possible in English by the Intergovernmental Oceanographic Commission (IOC) of Unesco, and in Spanish by the Food and Agriculture Organization of the United Nations (FAO).

2. Considering that during the meeting, a bibliographic summary related mainly to the phenomenon known as "El Niño"was presented, which is of utmost importance for those who investigate this phenomenon, it is recommended:

that the IOC give financial support to cover the cost of microfilm copying of the listed literature and the acquisition of equipment necessary for its reading, thus ensuring its availability to all interested institutions of the region.

3. Considering that the coordinated activities of the regional oceanographic investigations require the acquisition and exchange of scientific equipment, re-supply of research vessels and exchange of scientific personnel, it is recommended:

that the appropriate authorities in each country, especially the Customs authorities, facilitate the relevant arrangements.

4. It is recommended that countries on the west coast of South America jointly establish services for the determination of ship position. These are essential for further scientific work and would also be of great use for navigation, fisheries and other activities. For most purposes, an accuracy of 1-2 miles, as provided by the Omega system, is adequate; in order to obtain the greater accuracy needed for specific investigations, installation of high precision systems should be envisaged.

5. Bearing in mind the urgent need to initiate regional oceanographic studies, and that the participating scientists of the region (from Colombia, Ecuador, Peru and Chile) have agreed to initiate in their respective institutions and countries, and to carry out, coordinated cruises starting in 1975.

Considering furthermore, the existence of long-range extra-regional research projects during 1975, directed toward the verification of the possible occurrence of a new "El Niño" event, it is recommended:

that IOC be requested to promote a meeting of the countries (of the region) which are participating in the project "Regional Study of the Phenomenon known as 'El Niño'" (ERFEN), for the purpose of analyzing data obtained so far from the ERFEN cruises, and developing an integrated programme, and to co-ordinate, and bring fully into operation, the programme presented and approved by the above meeting.

6. It is recommended that a summary of the views expressed at the workshop, together with the recommendations, be communicated to the Joint Organizing Committee (JOC) for the Global Atmospheric Research Programme (GARP).

PHYSICAL

It is recommended:

Large-scale features

7. That a small group of experts be established by IOC with the assistance of the World Meteorological Organization (WMO) and possibly through the Scientific Committee on Oceanic Research (SCOR) to examine possible prediction schemes and indices for "El Niño" and to recommend research required in the further development of such schemes.

8. That the monitoring of significant features of large-scale atmospheric and oceanic circulations be improved by various means, including: use of satellite observations to monitor the position and intensity of the South Pacific high pressure centres; increased use of ships and island and coastal stations for the observation of surface atmospheric and oceanic parameters plus, where feasible, upper-air and sub-surface observations; improvement of the present arrangements for the dissemination of all such reports, thus ensuring wider distribution thereof; installation of tide gauges at appropriate locations, etc.

9. That the JOC for GARP review the various indices of large-scale atmospheric circulation for use by oceanographers in their study of "El Niño" phenomenon.

10. That the GARP studies on climatic change take into account the need to describe the variations of the atmospheric circulation pattern over the tropical and South Pacific so that a statistical evaluation of the degree of abnormality of these variations can be made.

Regional and local scales

11. That the monitoring of oceanic and atmospheric conditions within the region be intensified through the use of merchant and naval shipping and of island and coastal stations, with particular attention being given to factors such as the following:

(a) Equipping of selected ships of opportunity with expendable bathythermographs and thermographs or thermosalinographs, the data thus obtained to be disseminated through Integrated Global Ocean Station System (IGOSS) or some other appropriate system.

(b) Expansion of the existing regional network of upper-air observations to include twice-daily radiosonde and rawindsonde observations, with the addition of one station midway between Guayaquil and Lima, and with provision of additional support for existing stations (e.g., Galapagos) in order to ensure uninterrupted series of data.

(c) Appointment of port meteorological offices in the region and designation of a suitable coast radio station in order to obtain ship weather reports from the eastern part of the equatorial and South Pacific and from coastal waters along the west coast of South America, and to disseminate these promptly through the world meteorological network.

(d) Inclusion of sea level and surface salinity measurements in the observational programmes of island and coastal stations in the region.

(e) Use of suitably instrumented aircraft for mapping of sea-surface temperatures.

12. That regional monitoring programmes include a greatly enhanced description of the wind field, both near-shore and over the open sea, and additionally in at least a few locations on the continental shelf, direct measurements of horizontal water flow at various depths, possibly through use of profiling current meters.

13. That countries from the region, as well as scientists from other countries planning to work within the region, should exchange cruise plans in timely fashion, so that available resources can be used most effectively and opportunities for cooperation may be identified.

14. That the countries of the region establish a mechanism whereby oceanographic and meteorological data can be readily exchanged and made available. Until such a mechanism is established, investigation of "El Niño" phenomenon would be greatly facilitated if each country of the region were to designate a contact point for inquiries concerning data and were to make available inventories of their holdings of relevant data.

15. That early emphasis be given to the standardization and intercalibration of observational methods to be used in regional cooperative investigations and that assistance be provided to the laboratories in the region for the acquisition, calibration, maintenance and repair of instruments, possibly by providing access to the services of a comprehensive instrumentation centre.

16. That attention be given to special studies of the dynamics of both permanent oceanic fronts (e.g., the equatorial front) and fronts associated with coastal upwelling.

17. That the ERFEN Plan for regional oceanographic studies to be carried out in the next few years, as presented by Peru, be encouraged in principle.

Historical analysis

18. That studies of historical data, especially of long time series of geophysical data and in particular studies of the 1972 "El Niño" event, be encouraged; that the availability of relevant data be facilitated through the use of national contact points (see Recommendation No. 14) and that the results of such studies be made available at an early date.

19. That ship logbook meteorological data be made available for research purposes with minimum delay; that the World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC) assist in the preparation of inventories of historical holdings of relevant data; and that countries participating in the WMO Historical Sea-Surface Temperature Data Project accelerate the publication of their historical ship analyses as far back into history as would be meaningful for research into climatic variations.

BIOLOGICAL

It is recommended:

Particular systems

20. That the following studies be made of production in the coastal ecosystem:

(a) grazing effects;

(b) nutrition regeneration;

(c) scale; and

(d) variability.

21. That research on anchovy stocks should be strengthened by, inter alia:

(a) Studies on food particle-size distribution, the distribution of plankton in relation to the thickness of the photic and the physical (mixed) layers.

(b) Quantification of studies on biological indicator species and full analysis of data already on hand.

(c) Studies of the vertical distribution of anchovy eggs.

(d) An intense search, by means of laboratory experiments and other methods, of the critical density-dependence stage in the life-history of the anchovy.

(e) Studies of the possibility of relocation of anchovy to depths greater than those normally monitored.

(f) Studies on natural mortality through predation of anchovy.

22. That the participating countries be invited to consider the Peruvian monitoring scheme in their studies of economically important species. (See document "Biology of the Anchovy, Part 2: Projected Peruvian Research".)

23. That each participating country should accept responsibility for study of a major species occupying waters off its coast and carry out its work so as to make it as compatible as possible with the Peruvian anchovy scheme, depending on the importance of the resources to each country and the means available.

24. That each country should undertake to make observations on the presence in its waters of the species being studied by each neighbouring country.

25. That the participating countries institute a programme in biological oceanography within the ERFEN project, so that this develops into an integrated programme in biology and physics, responsive to analysis of "El Niño" events.

26. That steps be taken to establish a suitable mechanism by which the rapid exchange of information, data and samples, between participating countries, may be ensured.

27. Considering that some of the important fish species of the East Pacific Ocean biota off the South American coast have, in general, received littly study, it is recommended:

that countries of the region (Colombia, Ecuador, Peru and Chile) intensify their biological studies directed toward a better understanding of the ecosystem, in particular, of species of commercial importance, in order to ensure proper use of such resources.

3. PROCEEDINGS OF THE MEETING

GENERAL

The meeting was opened on the morning of 4 December 1974 with presentation of the review papers. A formal inauguration ceremony took place in the afternoon with the participation of the Executive Committee: Dr. Rómulo Jordán S., Chairman of the workshop; Capitán de Fragata (ret) Héctor Chiriboga; Capitán de Corbeta Raúl Toledo Echeverria, Director, Instituto Oceanográfico, Ecuador; Contralmirante Sergio Vásquez Pacheco, Comandante General de la Armada, Ecuador; Dr. Warren Wooster from the Rosentiel School, University of Miami; Capitán de Fragata Vicente Miño, Director de Desarrollo Marítimo, Ecuador; and Mr. Desmond P.D. Scott, Secretary, Intergovernmental Oceanographic Commission (IOC). Addresses were presented by Capitán de Corbeta Rául Toledo E. and Contralmirante Sergio Vásquez P.

Presentation of the review papers continued on Thursday, 5 December.

On Monday, 9 December, the meeting was addressed by Mr. Desmond P.D. Scott, Secretary, IOC; further papers were given and each group chairman presented a summary analysis of the review papers and a set of questions to which, in his view, the participants should direct their attention. In the afternoon, a brief plenary session was held, after which the groups separated. Further plenary sessions were held on each of the next two days.

The Steering Committee met on two mornings to discuss the progress of the meeting and to formulate a number of general recommendations for consideration by the workshop.

On the last day, Thursday, 12 December, each group presented its report and the recommendations were read out and formally adopted.

4. REPORTS OF THE SCIENTIFIC GROUPS

4.1 Report of the Physical Sciences Group

Scales

In considering "El Niño" phenomenon, one must recognize that several different scales are involved. Although it is generally agreed that the atmospheric disturbances are of global scale and that there are interactions among processes of all scales, for the purpose

of monitoring and forecasting, it is probably adequate to restrict consideration of the large scale to dimensions of the Pacific basin and more specifically to its tropical and subtropical zones, and to changes occurring in times of seasons to years. The regional (meso) scale comprehends the Pacific east of perhaps 100°W, from Panama Bight to central Chile. Here shorter times, of months to seasons, are particularly important. Finally, there are important manifestations of local scale such as coastal upwelling where the dimensions are some tens of kilometres offshore, and times of days and weeks must be considered. Within this local scale, the description of physical and biological processes and their relation to living resources are of particular importance.

The state of knowledge and the methods for monitoring and research differ from scale to scale as will become evident in subsequent sections.

Large-scale features

The "El Niño" phenomenon appears to be induced by anomalous behaviour of the large atmospheric circulation cells over the South and North Pacific Ocean. An appropriate measure of variations in these circulations would permit linking them with changes in ocean circulation such as those developed during "El Niño". The effects of the atmospheric circulation from northern hemisphere temperate latitudes into equatorial regions must be considered; conditions on the poleward side of the circulation cells should also be taken into account.

On the large scale, it has been proposed that "El Niño" occurs as a relaxation phenomenon after a prolonged period of intensified southeast trades has led to an accumulation of water in the western Pacific. When the trades then decrease in strength, the accumulated water flows back into the eastern Pacific. Circulation weakens off Peru as the current moves offshore during the spin-down, and surface waters warm as advection is decreased and exposure to incoming solar radiation is increased.

An index of the trade wind circulation has been developed by Quinn who uses a twelve-month running mean of anomalies of the atmospheric pressure difference between Darwin and Easter Island. Maximum values of this index are believed to indicate enhanced southeast trades and coincide with abnormally cold periods along the west coast of South America, while minimum values coincide with "El Niño" periods. It has been suggested that the magnitude of the pressure maximum and the timing and rate of subsequent decay of the pressure difference can be used for prediction of "El Niño" events.

The Quinn Index shows large values in late 1973 and early 1974, and Wyrtki has predicted an "El Niño" event similar to that of 1965 to begin in early 1975. There is not general agreement on this forecast. The index itself is only a crude measure of the strength of the southeast trades which may be significantly different in the eastern and western parts of the tropical Pacific. There is no other clear evidence of the likely onset of "El Niño" - equatorial surface temperatures remain below normal (October) and North Pacific observations of atmospheric circulation show no indication of a breakdown of the system. Unfortunately, sea level data are not yet available from the western Pacific, so the accumulation of water there cannot be verified.

It is unusual for two events to come at such short intervals (1972 and 1975), although there is some precedent in the unusual period of 1939-41. The use of a single index for prediction is hazardous; eventually, useful forecasts may be achieved through the use of a variety of indices whose evaluation is guided by physical reasoning. In the development of prediction schemes, oceanographers will need to know the minimum lead time required by those who would use the prediction; for example, in management of the anchovy fishery. Prediction schemes based on understanding of the physical processes involved are considered most likely to succeed.

Monitoring is required both for the development of improved indices and for understanding of the ocean atmosphere interaction and should include atmospheric pressure, winds and sea

level along with other elements. Programmes exist whereby these elements are monitored but the system needs to be significantly strengthened and the availability of the resulting data greatly accelerated. Remote sensing from satellites gives useful information on clouds and their movements and on sea surface temperature in cloud-free areas. Monitoring of sea level could be enhanced in the vast regions between islands through the use of bottom pressure gauges.

Investigations of the "El Niño" phenomenon are related to studies of climate within the objectives of the Global Atmospheric Research Programme, and it is desirable that "El Niño" investigations be coordinated with GARP.

Regional and local scales

In considering the development of cooperative investigations that could lead to understanding and to useful prediction of the development of "El Niño" conditions, a number of pertinent questions were identified; these are listed on page 14.

Monitoring of ocean and atmosphere in the eastern tropical and South Pacific is essential to studies of the "El Niño" phenomenon. There needs to be a much more effective use of ships of opportunity, especially those on regular runs from Panama to the western south Pacific, and those operating along the west coast of South America. It would be useful for some of these to be equipped with expendable bathythermographs and with thermographs or thermosalinographs. Possibly, an enhanced monitoring system using such ships can be developed within the framework of the Integrated Global Ocean Station System (IGOSS). Already the Bathy Pilot Project of IGOSS is yielding 1 500 observations per month; emphasis on the eastern south Pacific might significantly increase this number. It is evident, however, that data of this sort require a significant effort in analysis.

In the future, the availability of merchant ship data may be greatly increased by having port meteorological officers in several ports of western South America and by having a suitable radio station in the region to elicit, receive and retransmit the data in timely fashion.

Aircraft equipped with infra-red radiometers are particularly useful for obtaining synoptic pictures of coastal water surface temperatures. Subsurface temperatures can also be measured from aircraft by using expendable bathythermographs. Devices are also available for determining surface currents and transport from aircraft. In general, monitoring on the local scale can be done effectively from a suitably instrumented aircraft; plans are being developed to use such a facility off the Peruvian coast during 1976-77.

Monitoring on the regional and local scales should include direct measurement of current velocity as a function of depth, using instruments such as current profiling meters. Precise navigational control is required if this technique or the tracking of drifting buoys is to be done from a drifting ship. It was considered desirable that the appropriate agencies of the countries of the region should pool their efforts to develop a common system for the determination of ship position, thus making possible research requiring position control as well as being of great utility to navigation, fisheries, etc.

A three-dimensional picture of the atmosphere is also required; this requires additional observations by radiosonde and rawind equipment. Suggested positions are at the equator (Galapagos), Guayaquil (2°S), Lima (12°S), and at a position midway between Guayaquil and Lima. Three of these stations already exist but require strengthening to ensure an uninterrupted series of twice-daily observations. Description of the surface wind field needs to be significantly improved, so that useful values of wind stress and of curl of the wind stress will be available. The latter requires that observations be made offshore as well as along the coast. For the offshore measurements, buoys such as those used at Oregon State University appear appropriate, especially for use during intensive periods of study.

Cooperative programmes of research at sea by institutions of the region can be used for the study of specific problems. As noted earlier, an "El Niño" event has been forecast for early 1975 and arrangements have been made in the United States for a research vessel to work in the region from Ecuador west beyond Galapagos and south to 15°S, to verify the forecast and to observe features of the event, including the various sources of warm surface water. It appears that cruises of Colombia, Ecuador and Peru can be scheduled at about the same time so that comprehensive coverage of the region can be achieved. This will be of considerable value even if "El Niño" does not occur.

Regional cooperation in research

A proposal for regional cooperation in a study of the "El Niño" phenomenon was reviewed by the physical sciences group which endorsed it and urged its early implementation. Such a project, which is intended to continue at least through this decade, will bring together ongoing national programmes in the region and will strengthen them through improved coordination of observational programmes and of data analysis and interpretation.

Discussions of details of the proposal brought forth comments on various scientific and organizational aspects. Although the seasonal cruises proposed do not sample shorter period changes adequately, interpolation between seasons can be made through use of ocean station observations and through increased use of merchant and naval shipping in the region. For this purpose, it would be useful if observations at the coastal and island stations included sea level and surface salinity in addition to those parameters already proposed.

With regard to the spatial distribution of observations on the seasonal cruises, it was noted that a meridional section between Ecuador and Galapagos would permit determining the seasonal position and strength of the equatorial front; southward extension of this section would permit examination of important zonal flows such as the equatorial undercurrent and the south equatorial countercurrent. Spacing of the offshore sections, of observations along these sections, and of samples below the surface, should be carefully considered in the light of what is known about circulation and distribution of properties within the region and of the resources of the laboratories concerned.

The capability to measure certain properties, such as temperature and salinity, as continuous functions of depth using instruments such as the STD, should be added when practicable. The importance of current measurements at various depths was recognized, although at first this may only be possible at a few locations on the shelf. It was apparent that implementation of the full programme of seasonal observations would take time and that one of the principal difficulties would be in obtaining the necessary equipment and in keeping such equipment calibrated and in repair. Access to the services of a comprehensive instrumentation centre would be of great assistance. The cooperation of manufacturers will also be required in the supply of replacement parts and in the improvement of design.

With regard to organization of the coordination mechanism for the project, it was felt that working groups on a number of specific problems would be required; these might include groups on regional monitoring from ocean stations and shipping, on standardization and intercalibration, and on data and information exchange.

The proposed extension of the IMARPE monthly surface temperature charts to include data from other countries of the region was strongly endorsed, it being considered that these analyses would be of great value to all scientists engaged in investigation of the "El Niño" phenomenon.

It was noted that numerical models can be used to simulate many features of circulation in the eastern and equatorial Pacific under normal and anomalous conditions. Such models can be used to explore alternative hypotheses but are not likely to be useful for prediction in the near future.

The necessity for obtaining a three-dimensional picture of the hydrographic and flow structure was emphasized in order for the mass balance to be determined. In coastal waters, strong fronts are often present and are likely to be inadequately sampled with the classical station spacing. Because of both the physical and biological significance of these features, studies of the location, strength and dynamics of fronts should have special attention.

Historical analyses

Better understanding of the "El Niño" phenomenon is likely to come from an extensive analysis of the period 1971-73, when both extremes of conditions in the atmosphere and ocean occurred. Such an analysis will require access to coastal and merchant ship data that do not ordinarily find their way into data centres in addition to using satellite data that were collected during the period.

In attempts to analyse these and other historical data from the region, it is often difficult to obtain the data or even to know what data are available. This difficulty could be resolved through establishment within the region of a mechanism for the collection and exchange of meteorological and oceanographic data. Such a mechanism could provide important assistance, for example, to those engaged in study of the 1972 event referred to earlier. As an early step, an inventory of data holdings should be compiled.

Within the historical record there exists some long-time series of geophysical data, for example, rainfall at Piura in northern Peru, that can be analysed to reveal dry and wet regimes related to "El Niño". Power spectrum and correlation analyses of the Puerto Chicama fifty-year surface temperature record have been carried out. Other long series should be sought and the possibility examined of extending the study of dry and wet regimes further back in time through use of tree rings and varved sediments. In suggesting this sort of research, it is recognized that because of the non-linear nature of the ocean-atmosphere system, the analyses are unlikely to reveal periodicities useful for prediction.

4.2 Report of the Biological Sciences Group

The Biological Group took as basis for its discussions a set of questions under six headings formulated by its chairman and rapporteurs. Although these discussions did not lead to formal conclusions with regard to the biotic characteristics of South American coastal waters under "El Niño" conditions, they directed attention to important aspects of those characteristics and to the formulation of questions for discussion with the physical oceanographers. The discussions of the Biological Group are reported here under their main headings.

Effects of "El Niño" on the primary and secondary production in the coastal upwelling ecosystem

Primary production in the subject area is generally high, and the values of ^{14}C uptake measurements obtained even during "El Niño" conditions are greater than those of tropical surface waters. Production rate varies according to distance from the coast, composition (diatoms, flagellates) of the plankton populations. ^{14}C uptake experiments have shown that the rate of production falls during "El Niño" conditions to one third of the value they show during non-"El Niño" conditions. The variations in production are associated with variations in upwelling which are assumed to be associated with variations in wind strength. Nevertheless, the paper by Zuta et al. shows that the winds at Chimbote, Callao and San Juan in 1971 were the same in strength and velocity as those of 1972 and 1973. They were expressed as monthly averages at shore stations; a gale in the right direction for 2½ days a month should provide one deviating observation in each year, but none is recorded, so perhaps the monthly averages express a true trend; such observations were supported by those taken at sea. Thus, upwelling should occur even during "El Niño" and perhaps shown by the upward slope of the 15°C isotherm toward the coast. During "El Niño", ^{14}C uptake measurements were reduced from 1.0 $gC/m^2/d$ to 0.3 $gC/m^2/d$ which, however, as remarked earlier, is greater than that of tropical surface waters (0.1 $gC/m^2/d$). The average productivity in the eastern tropical Pacific may be somewhat higher, but "El Niño" water may not have originated there (i.e., from the equatorial countercurrent). The question arises: Is the production cycle during "El Niño" that of tropical surface waters or that of a modified upwelling system?

The variation of primary production is bound to have its effect on the anchovy, but the nature of the effect will depend upon the degree to which the anchovy, in any of its life stages, depends upon phytoplankton and on the degree to which that dependence is related to composition of the phytoplankton; it will also be affected by the changes the anchovy can make in its diet in response to a changing biological environment.

The group recognized that questions existed as to:

(a) grazing effects;

(b) regeneration of nutrients;

(c) the area with respect to which measurements should be made; and

(d) the relation between mean and extreme conditions.

Biology of anchovy under normal conditions

Recently obtained results from marking operations suggest that the longevity of the anchovy is somewhat greater than has been supposed until now; the discussion of the circumstances of recovery of the marks showed that the results have a good measure of confidence and must be taken into account; the consequence for population models is bound to be important.

Discussion of anchovy feeding habits directed attention to evidence that suggests a genetic or racial separation between anchovy of the southern zone off Chile and those of the central and northern zone off Peru. Data on meristic characters (gill raker and vertebral number), gut morphology, the location and timing of spawning, feeding habits and growth and the pattern of recruitment, suggest that these may be distinct stocks. As well as having fishery management significance, such a racial subdivision of the population may be of importance in relation to possible regional differences in the effects of the "El Niño" type of environmental change - which may differ in nature, timing and magnitude in different parts of the subject area - and on biotic processes (reproduction, growth and survival) governing the size and composition of the exploitable biomass. It is therefore recommended that further attention be paid to this problem in future research on anchovy with a view to determining:

(a) the degree of racial distinction (including genetic) between the stocks in the two areas;

(b) if distinct (i) their respective limits of distribution and rates of mixing, (ii) the differences in their main population characteristics governing their production (reproduction, survival, growth); and (iii) the difference in their food and feeding habits in their main life history stages.

Still in connexion with feeding, questions must be asked about the age of which the anchovy starts and/or stops feeding on phytoplankton and to what degree a zooplankton element of the diet might be necessary for successful maturation. Studies should be undertaken on the matter of particle-size in relation with anchovy feeding, the thickness of the photic layer in respect of distribution of plankton and consequentially of the anchovy, and of density of the organisms on which anchovy feeds.

Biotic indicators of anomalous ocean circulation patterns

There is no doubt about the force of biotic qualitative evidence from changes in populations of the crab Euphyllax and of the guano birds, as indications of the changes in water characteristics that take place during "El Niño", but there are serious problems concerning the quantification of this evidence; the timing and location of an invasion by an indicator species can be quantified from presence and absence data, but some doubt was expressed about quantification of the rate of invasion - opinion was also expressed that an indicator species could be a definer of a boundary of an advection process. It was also

felt that insufficient use was being made of data relating to the guano birds which react very rapidly to changes in the anchovy population.

Biology of the anchovy under "El Niño" conditions

Although the evidence is quite clear that spawning in 1971 was at a low level and that the cohort of recruits resulting from it was exceedingly poor, it is impossible to say whether poor recruitment resulted directly from the weak spawning or from heavy mortality at some juvenile stage or, if it were the latter, the cause thereof; nevertheless, although the failure of the 1971 cohort cannot be indubitably attributed to "El Niño", the cohorts of 1972 and 1973 were low because of "El Niño" conditions.

The possibility that there had been a perturbation of the maturation cycle was discussed in some depth. The possibility that the advance of "El Niño" conditions (into the area habitually inhabited by the anchovy) could have signalled changes and induced a change in the maturation cycle was thought by some to be unlikely because the number of eggs produced in 1971 was only a little lower than that in 1970.

Evidence as to proportion of stock observed in spawning condition, change in fat content, change in age and size composition of the stock and change in growth rate, was discussed. It was argued, from the size/fecundity relation, that change in stock composition could not account for change in numbers of eggs in the sea, but the evidence on age and size composition of the stock during 1971 is not sufficiently precise to resolve the question. Some members of the group thought that whatever might have been the change in maturation cycle, it could not have been caused by "El Niño", and hence that the change in recruit class strength had its origin in the operation of the stock/recruit relation. There is a conflict between estimates of biomass and estimates of egg numbers. If the biomass estimates from cohort analysis are right, the 1971 cohort was spawned at high stock and the stock/recruit danger did not then exist. If the egg estimates are right, the 1971 cohort was spawned at low stock and may have failed due to the stock/recruitment relation.

Another member felt that the association of the change in level of recruitment with "El Niño" conditions seemed to be a most unlikely coincidence, but it was pointed out that year-class failures had been observed elsewhere (in other species) when neither heavy fishing nor extreme environmental conditions prevailed and hence it was argued the change in anchovy recruit class might well have taken place independently of "El Niño" conditions. Among mechanisms that might have operated, a change in quality distinct from quantity of spawn was one which ought to be examined, considering evidence from California sardine with regard to variation in egg size and to associated survival of larvae.

The matter of the estimate of the eggs in the sea was discussed, chiefly with respect to sampling practices and it was pointed out that sampling with the Hensen net might be missing a substantial proportion of the eggs lying at depths greater than those that this net samples. It was agreed that further work ought to be done with regard to vertical distribution of the eggs.

Some discussion took place of evidence with regard to larvae and the mortality to which they are subject, but an opinion was expressed that larval mortality cannot yet be measured because the work is subject to two ambiguities: first, as to temperature dependence of larval growth rates and, second, as to its dependence on food availability, both of which could operate to modify the duration of the larval interval and hence to affect the estimate of numbers present. Nevertheless, it was thought that an intense search should be made for the critical density-dependent stage among the juvenile stages.

The account given of the changes in anchovy abundance associated with "El Niño" made reference to evidence of important variations in accessibility and vulnerability of the anchovy and some attention was given to variations in vertical and horizontal distribution; it was agreed that in future work, studies should be made to examine the possibility that the fish are displaced to depths greater than those at which they are normally observed.

Fishery consequences of "El Niño"

Reference was made to changes in populations of skipjack, tuna, merluza and the Pacific herring (Opisthonema). Observations from the Chilean and Ecuadorian areas were discussed in this connexion and a reference was made to observation of an oxygen deficient layer in Chilean waters.

The discussions were extended to take note of changes in the tuna fisheries of the entire eastern coastal Pacific and reference was made to changes in year-class strength and distribution of the different species, especially of skipjack.

Changes in benthic species, especially in Chilean waters, were discussed and a suggestion was made that such changes might be indicative of "El Niño" conditions; however, it was felt that monitoring of changes in benthic stock would not prove, operationally, to be a useful method of following "El Niño" changes.

Effect of "El Niño" on the predators of anchovy

Although there was no reason to doubt that changes in anchovy availability had affected the guano birds, it was thought that more attention might perhaps have to be given to identification of the predators upon the birds and measurement of the intensity of their effect. Similarly, it was thought that a closer look might be taken at the principles according to which the amount of predation upon the anchovy was estimated.

The foregoing discussion led to two sets of questions which can be answered only by physical oceanographic and meteorological investigations. The questions concerning the previous "El Niño" occurrences, especially the 1972-73, had the objective of obtaining data which could suggest an explanation of some biological aspects of the phenomenon. The second set of questions are concerned with future research. Answers to these latter questions can be the basis for planning the strategy of future observational studies.

I. Hindcast Questions

(i) Can the mesoscale regional and large-scale circulation be explained in enough detail that the advection of water masses can be related to data on indicator species? Such descriptions would permit the explanation of the origin of extra-regional species.

(ii) What is the thickness of the mixed surface layer in different areas of the Peruvian coast? These data need to be compared with euphotic layer thickness and related larval survival and other biological studies.

(iii) What are the horizontal and vertical differences in temperature and density (stratification) between the 1972-73 "El Niño" case and a typical year?

(iv) Are there any indications that the oxygen deficient layer was advected into the region during the 1971-73 period?

(v) Can a statistical study of coastal station sea-surface temperatures be correlated with offshore temperature and other data? It would be helpful to be able to understand the offshore regime from easily obtained time series data such as coastal temperatures. It is highly desirable to be able to estimate the environmental conditions during absences of oceanographic cruises.

II. Forecast Questions

(i) What set of oceanographic observations would be needed, extending from pre-"El Niño" conditions well into "El Niño" conditions, so as to be able to give an account of the environmental conditions encountered by an anchovy brood up to the time of its recruitment?

(ii) In what detail should an upwelling plume be described (how many transects, etc.) so as to be able to specify the sequence of events in the development, maintenance, and eventual dispersion of the phyto-and zooplankton populations on which an anchovy brood feeds?

(iii) What kind of joint programme might be planned and carried out with the aim of identifying the characteristics of "anchovy" water (for each of its aionomorphs) so that in the future studies might be made of the variation on behaviour and other characteristics of the anchovy?

It is emphasized that the "forecast" questions were formulated as a basis for discussion. The Biological Group expected to have to respond to questions from the physical oceanographers concerning time-scales, known and suspected relations between the anchovy and its environment, and similar matters, and then to collaborate with the physical oceanographers in designing suitable strategies for work along the lines suggested by the questions. This latter interaction was left for future meetings.

The Peruvian proposal for the regional project ERFEN sets out a plan for systematic work in physical and chemical oceanography for the purpose of monitoring the behaviour of the Peruvian current and associated systems, and for detecting the onset and describing the course of "El Niño". The Peruvian document "Biology of the Anchovy, Part 2: Projected Peruvian Research" describes the Peruvian system of monitoring the anchovy stocks and the lines of research to be undertaken with a view to deepening the knowledge of anchovy biology and to improving the models according to which the monitoring is carried out. This document thus sets out part of the biological counterpart to the ERFEN project, and was adopted as such by the Biological Group. The general value of the Peruvian scheme, as a logically arranged set of monitoring activities, was recognized and, although it was realized that few fisheries in the world could support the full array of activities, the scheme was recommended for consideration by other countries. The Peruvian anchovy scheme has the further advantage that it permits a distinction between elements which are properly the task of a mission-oriented institution such as IMARPE and elements which can be undertaken by other institutions, and hence it is a powerful mechanism for mobilizing international collaboration. The group considered that the IMARPE might find it useful to examine the comments, recorded above, on various aspects of research on anchovy biology and on its ecosystem, especially in relation to "El Niño" conditions. In addition, it was suggested that the ecological elements of the scheme could probably be strengthened and in particular that the stock responses to "El Niño" conditions might, as detected by this system, point the way to better understanding of the basic biology. Some technical suggestions with respect to the use of acoustic equipment and to identification of the point of critical mortality were offered.

The group also discussed the work in other areas, other species, and particular aspects of biology to round off the anchovy project into a comprehensive counterpart of the physical oceanographic programme. It was suggested that there was a need to undertake work on other economically important species in the area as hake, sardines, bonito, pinchagua and skipjack; one member of the group thought the study of flying fishes would be worthwhile. Proposals were made that each participating country would take up responsibility for the most important species in its area, each of which would be studied following the Peruvian anchovy scheme as far as the size of the resources, the facilities of the country and the need of the problems permit; furthermore, each country should make observations about the presence of the species in charge of other countries in the region. The following tentative list was proposed:

Species	Primary study	Secondary study
Hake	Chile	Peru
Anchovy	Peru	Chile
Pinchagua	Ecuador	Peru, Colombia
Sardine	Ecuador	Peru, Colombia
Bonito	Ecuador	Peru, Colombia
Skipjack	Ecuador	Peru, Colombia

After further consideration of the biological part of the project, the group suggested that participating countries should undertake a coordinated programme of primary and secondary productivity measurements using standardized methods, and the group prepared a statement (see page 15) on the minimum requirements of the observations needed for the programme. It was also thought essential for the success of the project that it should be coordinated with the physical oceanographic programme.

Some Physical Questions about "El Niño"

1. How large an ocean area is affected by "El Niño"? What is the sequence of events whereby anomalous conditions spread throughout this region?

2. What changes in the atmospheric circulation initiate the spread of anomalous oceanic conditions, and how are the atmospheric processes modified by the oceanic conditions? Why does the ocean-atmosphere system depart from, and return to, normal?

3. What measures of the atmospheric circulation are most practicable for use in developing "El Niño" prediction schemes?

4. What determines the sudden onset and decay and the mid-"El Niño" return toward normality as seen in Peruvian coastal temperatures? Can the timing of coastal indications be used to predict the timing of effects on the coastal ecosystem?

5. During "El Niño", how are the various elements of the coastal circulation modified, either in strength or position, for example, the coastal undercurrent and the offshore countercurrent?

6. What changes in vertical stability are occasioned by "El Niño"? What depths are affected?

7. What determines the differences among "El Niño" events in timing, duration and intensity?

8. To what extent are the coastal manifestations of "El Niño" brought about by lateral advection in the surface layer from the north and/or west and by changes in vertical advection? How do these processes relate to changes in the wind field?

Minimum Suite of Observations for the Biological Component of ERFEN

The attached plans reflect the deliberations of a committee of three in response to the chairman's question regarding the minimum suite of observations in space and time to measure primary, secondary and fish production.

The range of activities proposed spans the scale from upwelling and regeneration of nutrients, through the primary production, the grazing of anchovy and zooplankton, to the description of the anchovy position during spawning and seeding periods using sonar, sounder and spawning surveys.

(A) Special area study

The Chimbote area (see Figure 1a) has been intensively studied for several years. It is recommended that this area be monitored on a more or less continuous basis (Table I). This is a most important area of the fishery and a dense spawning centre and would seem the most useful area to conduct intensive research which would be impossible over the whole area of distribution of the anchovy.

The chief objective of the work in the Chimbote area would be to construct an elementary model of production and grazing which includes terms for primary production, diffusion, transport into and out of the area, grazing by juvenile and adult anchovy, predation, grazing by invertebrate primary herbivores, within which the survival of anchovy from egg to recruitment can be estimated from year to year. The elementary model for the Chimbote area will be a focus for less comprehensive but broader scale study in time and space of the feeding, reproduction and growth of the main anchovy stock.

The sampling effort in the Chimbote area would measure temperature salinity NO_3, SiO_3, O_2, Chl "a", ^{14}C uptake, phytoplankton grazing (by zooplankton and fish), light penetration and currents to 200 metres, fish eggs, fish larvae, fish juveniles, as specified under Station types "A", "B" and "C" in the attached Table II parameter sheet. The "A" Station, or full complement station, includes analytical biological, chemical and physical oceanography. The "B" Station will be a reduced version with only a full physical oceanographic suite of measurements. The "C" Station is primarily a fish egg and larval station. Cruise frequency is listed in Table III.

(B) Wide area study

The general limits of the wide area study are shown on the enclosed sketch of the Peruvian coast (see Figure 1). The Chimbote area is seen to be less than 5 percent of the total area but one-third of the full complement stations, one-tenth of the oceanographic stations and one-twentieth of the fish spawning survey and upwelling stations would be worked there. The objective along the entire coast is to sample adequately the zone which has at its centre the origin of the upwelled water, the mixing zone and the offshore zone. Including the Chimbote area, there are 4 sections with 3 stations for the full complement stations and, in addition, 3 oceanographic sections make a sample transect density of ca. one station per 120 n mi. The fish spawning survey lines are placed at 40-mi intervals in the innermost 60 mi in addition to the sampling the full length of the oceanographic sections.

It is recommended that the analytical models of production be coupled with regional oceanography and anchovy biology studies for maximum ship-time efficiency. The enclosed Table V list of anchovy evaluation points may be coupled closely with the production model.

TABLE I

Special area study, Chimbote Section

(See Figure 1a)

Measurement at stations:	5 "A"-Stations 6 "C"-Stations
Underway measurements:	Radiant energy Surface chlorophyll Sonar mapping Echosounder integrator

TABLE II

Parameters to be measured at stations

Parameters	Station types		
	A	B	C
Egg and larval samples	0-200 m	0-200 m	0-200 m
Chlorophyll "a" standing stock	0-200 m	0-200 m	Surface
Phaeophytin	0-200 m	0-200 m	
Light penetration	0-200 m	0-200 m	0-200 m
Zooplankton volume	0-200 m	0-200 m	0-200 m
$T^{\circ}C$	0-500 m	0-500 m	0-500 m
S °/oo	0-500 m	0-500 m	0-200 m
NO_3	0-200 m	0-200 m	0-200 m
SiO_3	0-200 m	0-200 m	0-200 m
O_2	0-500 m	0-500 m	0-200 m
^{14}C uptake	0-200 m	Surface	
Phytoplankton size distribution	0-50 m	0-50 m	
Microzooplankton size distribution	0-50 m	0-50 m	
Juvenile anchovy 2 m IKMT, 2 mm mesh	Night samples to 200 m	Night samples to 200 m	
Current estimates	Drogue and geostrophy	Drogue and geostrophy	
Phytoplankton species composition	0-200 m		
Zooplankton species and stages	0-200 m		

TABLE III

Frequency of cruises - Density of transects and stations

Cruise frequency per year					
Least:	- September - December - March - June	Monitor:	August September October December - March - June	Analytical:	August September October December January March April June

Transect density	
Full complement each 240 miles ("A" stations)	(4 transects)
Full oceanography each 120 miles ("A" and "B" stations)	(7 transects)
Fish spawning survey each 40 miles ("A", "B" and "C" stations)	(21 transects)
Upwelling survey each 20 miles (underway profiles)	(42 transects)

Transect length		
Full complement	4 at 120 miles	("A" stations)
Full oceanography	7 at 240 miles	("A" and "B" stations)
Fish spawning	7 at 240 miles	("A" and "B" stations)
	14 at 50 miles	("C" stations)
	21 at 10 miles	("C" stations)

Station density on a transect				
Station Type	"A"	Full complement	10, 50 and 120 miles	12 stations on 4 lines (3 extra in Chimbote area)
	"A" and "B"	Full oceanography	10, 30, 50, 70, 90 120, 180, 240 miles	56 stations on 7 lines
	"A" and "B"	Fish spawning	10, 30, 50, 70, 90 120, 180, 240 miles	56 stations on 7 lines
	"C"	Fish spawning	10, 30, 50 miles	42 stations on 14 lines
	"C"	Fish spawning	10 miles	21 stations on 21 lines
	Total			119
	Upwelling survey	Underway and indicated profiles depending on plume and front formation		

TABLE IV

Additional studies in selected areas

Intensify the studies, in selected areas, of the following parameters, in order to measure variation in time and space and their relation with the fisheries:

A Inshore water - offshore - mixed water

T, S, NO_3, SiO_3, O_2, Chl "a", ^{14}C

Grazing phytoplankton, zooplankton, light and currents
Measurements at 0-200 m

B Surface sample

Chl "a", light, T, S, O_2, NO_3, SiO_3

Phytoplankton

C Euphotic sample

T, S, NO_3, SiO_3, O_2, Chl "a", light, ^{14}C

Phytoplankton and zooplankton

TABLE V

Anchovy evaluation points

Anchovy evaluation points	Competition for food	Predation	Disease
Spawning female condition	X		(X)
Egg survival		X	
Yolk sac larvae survival		(X)	
First feeding dinoflagellate larvae survival	X	X	
Nauplius-feeding larvae survival	X	X	
Initiate schooling larvae survival	(X)	X	
Metamorphosis survival	X	X	
Juvenile survival and growth	X	X	(X)

AREA STUDIES

Fig. I : WIDE AREA STUDY

Total number of stations:

15	A	⊗
43	B	o
61	C	x
Total 119		

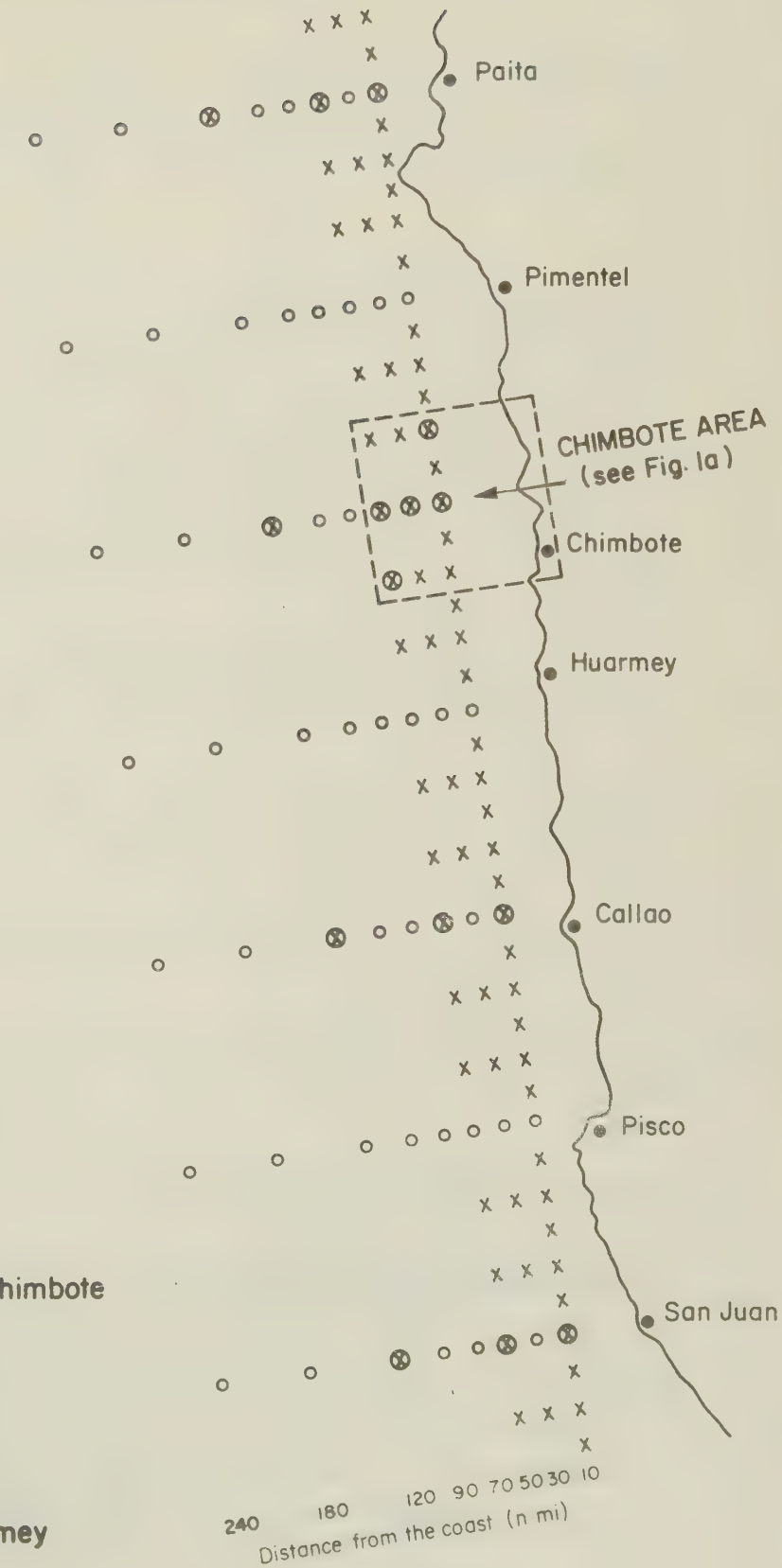
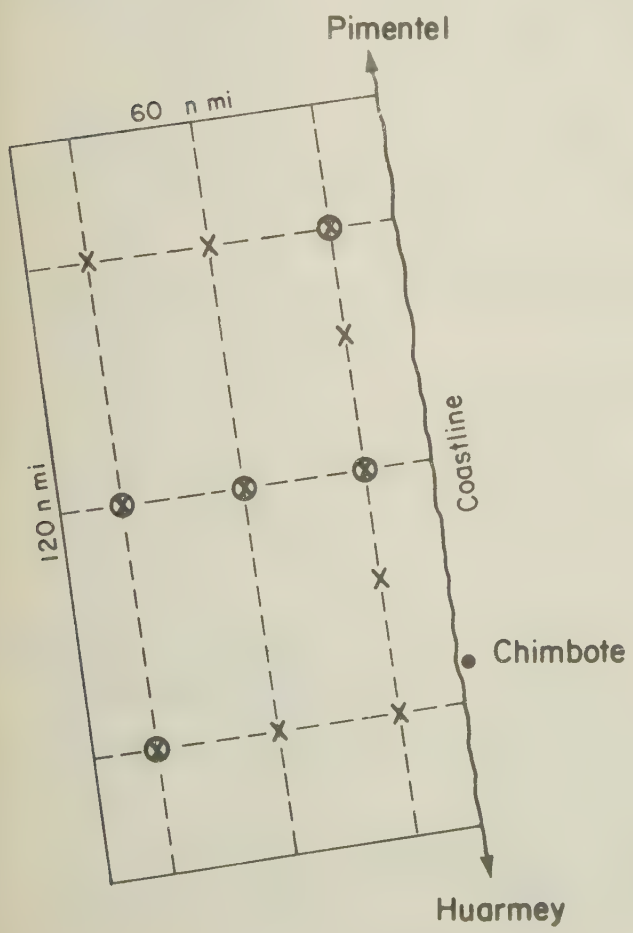


Fig. Ia : CHIMBOTE AREA
(Special area study)



5. LIST OF PAPERS PRESENTED (OR DISTRIBUTED)

Topic	Title	Author
1	Ocean–atmosphere interaction of large time and space scales	Jerome Namias
2	Meteorological aspects of the 1972–73 "El Niño" Phenomenon	Colin Ramage
3	Physical aspects of the 1972–73 "El Niño" Phenomenon	Salvador Zuta, David B. Enfield Jorge Valdivia, Pablo Lagos and Carlos Blandin
4	Biological aspects of the 1972–73 "El Niño" Phenomenon Part 1: Distribution of the Fauna	Aurora Ch. de Vildoso
4	Biological aspects of the 1972–73 "El Niño" Phenomenon Part 2: The Anchovy Population	Julio Valdivia
5	A Review of Recent Research on the Circulation of the equatorial and eastern South Pacific Ocean	Klaus Wyrtki
6	Investigations of coastal upwelling processes	Robert Smith
7	The Water Masses in the Region North of Chile and their variations in a cold period (1967) and in a warm period (1969, 1971 and 1973)	Fernando Robles Elias Alarcón Alvaro Ulloa
7	Water Masses and Circulation in the Southeast Pacific Ocean – Latitudes 18–33°S (Operation MARCHILE VIII, 1972)	Hellmuth A. Sievers C. Nelson Silva Sandoval
7	Primary Productivity of the coastal and oceanic waters of the Northern and Central Chile (Operation MARCHILE VIII, 1972)	Boris Ramirez R. Sergio Palma G. Héctor Barrientos C.
8	The Peru Current System, Part 1: Physical aspects	Oscar Guillén G.
8	The Peru Current System, Part 2: Biological aspects	Haydee Santander B.
9	The Region North of the Equatorial Front, Part 1: Physical aspects	David B. Enfield
9	The Region North of the Equatorial Front, Part 2: Biological aspects	Roberto Jimenez S.
10	Models in Marine Ecology	David H. Cushing
11	Biology of the Anchovy, Part 1: Summary of the present knowledge	Rómulo Jordán S.
11	Biology of the Anchovy, Part 2: Projected Peruvian Research	Geoffrey L. Kesteven
12	Effects of Environmental Variations on the Distribution of Marine Fauna	Marta Vannucci
13	Estimation of the Effects of Environmental Variations on the eggs and larvae of the Northern Anchovy	Reuben Lasker and Paul E. Smith
–	Bibliography on "El Niño" and associated publications	Merritt Stevenson
–	Characteristics of the "El Niño" Phenomenon and influence of the Humboldt's current on the Ecuadorian coasts	Carlos Blandin
–	Project ERFEN Regional Study of the "El Niño" Phenomenon	IMARPE
–	The "El Niño" of 1972 in the eastern tropical Pacific Ocean	Forrest R. Miller
–	The Fishery of Skipjack in the Eastern Pacific Ocean	Eric D. Forsbergh

6. LIST OF PARTICIPANTS IN THE WORKSHOP ON THE PHENOMENON "EL NIÑO"

Dr. Richard Barber
Coastal Upwelling Ecosystems
Coordinator - National Coordination Center
Duke University, Marine Laboratory
Beaufort, North Carolina 28516
U.S.A.

Dr. David H. Cushing
Fisheries Laboratory
The Esplanade
Lowestoft, Suffolk
United Kingdom

Dr. Gotthilf Hempel
Institut für Meereskunde an der
Universität Kiel
23 Kiel
Düsternbrooker Weg 20
Federal Republic of Germany

Dr. Alan Longhurst*
Institute for Marine Environmental Research
67 Citadel Road
Plymouth, Devon
United Kingdom

Dr. Jerome Namias
Scripps Institution of Oceanography
P.O. Box 1529
La Jolla - California 92037
U.S.A.

Dr. James O'Brien
Director, Physical Oceanography
Office of Naval Research
Arlington, Va. 22217
U.S.A.

Dr. Basil Parrish
Marine Laboratory
Victoria Road
Torry, Aberdeen AB9 8DB
Scotland
United Kingdom

Dr. Colin Ramage
Department of Meteorology
University of Hawaii
2525 Correa Road
Honolulu, Hawaii 96822
U.S.A.

Dr. Paul E. Smith
Southwest Fisheries Center
NOAA-NMFS
P.O. Box 271
La Jolla - California 92038
U.S.A.

Dr. Robert Smith
School of Oceanography
Oregon State University
Corvallis, Oregon 97331
U.S.A.

Dr. Merritt Stevenson
Interamerican Tropical Tuna Commission
Scripps Institution of Oceanography
P.O. Box 1529
La Jolla - California 92037
U.S.A.

Dr. Susumu Tabata
Research Scientist
Environment Canada
Marine Science Branch
512 Federal Building
Victoria, British Columbia
Canada

Dr. Matthias Tomczak
Institut für Meereskunde an der
Universität Kiel
23 Kiel
Düsternbrooker Weg 20
Federal Republic of Germany

Dr. Klaus Wyrtki
Department of Oceanography
University of Hawaii
2525 Correa Road
Honolulu, Hawaii 96822
U.S.A.

Dr. Warren Wooster*
Rosenstiel School of Marine and
Atmospheric Science
University of Miami
4600 Rickenbacker Causeway
Miami, Florida 33149
U.S.A.

---

* Members of the Steering Committee

Regional Invited Experts

Ing. Héctor Ayan
Instituto Oceanográfico de la Armada
Casilla 5940
Guayaquil
Ecuador

CPCB Carlos Blandin
Servicio Meteorológico
Avenida 10 de Agosto 2627
Quito
Ecuador

TNFG Pedro Cabezas
Instituto Oceanográfico de la Armada
Casilla 5940
Guayaquil
Ecuador

Dr. Daniel Dossman M.
Departamento de Biología
Universidad del Valle
Apartado Aéreo 2188
Cali
Colombia

Dr. David B. Enfield
Instituto Oceanográfico de la Armada
Casilla 5940
Guayaquil
Ecuador

Ing. Oscar Guillén G.
Instituto del Mar
Casilla 3734
Callao
Peru

Dr. Roberto Jimenez S.
Instituto Oceanográfico de la Armada
Casilla 5940
Guayaquil
Ecuador

Dr. Rómulo Jordán S. (Chairman)
Instituto del Mar
Apartado 3734
Callao
Peru

Dr. Pablo Lagos
Instituto Geofísico del Perú
Apartado 3747
Lima
Peru

CPFG Jaime Sanchez C.*
Comisión Colombiana de Oceanografía
Apartado Aéreo 28466
Bogotá
Colombia

Dr. Alfredo Sanchez R.
Biólogo Pesquero
Técnico División de Recursos Naturales
Departamento Nacional de Planeación
Carrera 13, No. 26-45
Oficina 412
Bogotá
Colombia

Mr. Hellmuth A. Sievers C.
Instituto Hidrográfico de la Armada
Casilla 324
Valparaiso
Chile

Mr. Nelson Silva S.
Centro de Investigaciones del Mar (CIMAR)
Universidad Católica de Valparaíso
Casilla 1020
Valparaiso
Chile

Mr. Julio Valdivia
Instituto del Mar
Apartado 3734
Callao
Peru

Mr. Jorge Valdivia P.
Servicio Nacional de Meteorología e Hidrología
República de Chile, n° 295 - Oficina 205
Lima
Peru

Dra. Aurora Ch. de Vildoso
Instituto del Mar
Esquina Gamarra y General Valle s/n
Apartado 3734
Callao
Peru

International Organizations

Dr. Agustín Ayala-Castanares
Vice-Chairman of the IOC
Coordinador de la Investigación Científica
Universidad Nacional Autónoma de México
Apartado Postal 70-157
Mexico 20 D.F.
Mexico

Mr. Daniel Behrman
Unesco
Science Sector
Place de Fontenoy
75700 Paris
France

Dr. Luis Capurro
IOC, Unesco
Place de Fontenoy
75700 Paris
France

Mr. Geoffrey L. Kesteven*
Director, FAO/UNDP Peru 008
Instituto del Mar
Apartado 4480
Lima
Peru

Mr. Max H. Mull
Chairman, CMM Working Group on Marine Meteorological Services System
National Weather Service (W 162)
Silver Spring, Md. 20910
U.S.A.

Mr. Desmond P.D. Scott
Secretary IOC, Unesco
Place de Fontenoy
75700 Paris
France

Dr. Marc Steyaert
Unesco - Division of Marine Sciences
Place de Fontenoy
75700 Paris
France

Dr. Gerhard Tomczak
FAO Fishery Resources Officer
Department of Fisheries
Via delle Terme di Caracalla
00100 Rome
Italy

Dr. George Verploegh
Chief, Ocean Affairs Branch
Marine and Aeronautical Division WMO
41 Avenue Giuseppe Motta
1211 Geneva 20
Switzerland

Observers

Dr. Luis Arriaga
Secretario Científico
Comisión Permanente del Pacífico Sur
Bellotas n° 126 (Providencia)
Santiago
Chile

Tnte. E. Bravo
Dirección de Hidrografía y Navegación de la Marina
La Punta
Callao
Peru

Miss Ruth Calieras
Instituto del Mar del Perú
Esquina Gamarra y General Valle s/n
Apartado 3734
Callao
Peru

Miss E. Carcamo
Instituto Nacional de Tecnología
ITINTEC
Lima
Peru

Mr. Ronald I. Currie
Scottish Marine Biological Association
Dunstaffnage Marine Research Laboratory
Oban, Argyll
Scotland
United Kingdom

Dra. Maria E. Chamorro
Ministerio de Pesquería DGIOT
Lord Cockrane 351
Lima
Peru

Dr. J. Dunn
Interamerican Geodetic Survey
Washington D.C.
U.S.A.

Mr. Victor Gallardo
Woods Hole Oceanographic Institution
Woods Hole, Massachussets 02543
U.S.A.

Mr. George E. Hemmen
The Royal Society
6 Carlton House Terrace
London SW1Y 5AG
United Kingdom

Dr. William J. Merrell
Office of the IDOE
National Science Foundation
1800 G Street N.W.
Washington D.C. 20550
U.S.A.

Srta. N. Ochoa
Instituto del Mar del Perú
Esquina Gamarra y General Valle s/n
Apartado 3734
Callao
Peru

Mr. V. Rioseco
Consul de la República de Chile en Ecuador
Guayaquil
Ecuador

Dra. Haydee Santander
Instituto del Mar del Perú
Esquina Gamarra y General Valle s/n
Apartado 3734
Callao
Peru

Tnte. Cesar Vargas Faucheux
Dirección de Hidrografía y Navegación
de la Marina
La Punta
Callao
Peru

Dr. Lloyd Dickie
Institute of Oceanography
Dalhousie University
Halifax, Nova Scotia
Canada

Dr. Héctor Inostroza V.*
Instituto de Pesquisas Espaciais
Projecto SERE - Grupo RECMAR
Avenida dos Astronautas 1758
12.200 - São José dos Campos - SP
Brazil

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